Brief Overview of Results and Accomplishments – Part 1

The research under the ORC program of Renewable Energy technologies and Health was highly multi-disciplinary, ranging from health to engineering and technologies. Also, more emphasis was given to research related to wind energy. Graduate students from different academic departments were supported by the ORC program. Faculty members who collaborated with the Research Chair and directly contributed to the research program include: Profs Philip Bigelow, Laurie Hoffman-Goetz, Jane Law, Shannon Majowicz, and Stephen McColl from the Faculty of Applied Health Sciences, and Profs Fue-Sang Lien and Zhongchao Tan from the Faculty of Engineering.

Studies on sleep disturbance was one of the topics undertaken in researching the effects of industrial wind turbines. The research team conducted a number of observational studies in residents living at various distances from wind turbines. In one of the initial studies, twelve participants living within a few kilometers of turbines at a wind facility and ten participants over 10 km from the closest wind turbine were studied. Although sleep parameters, based on acitgraphy and sleep diaries, were poorer for those living closest to the wind turbines, after controlling for potential confounders in a logistic regression model the differences were not significantly different. Measurements of sound pressure levels within the participants' bedrooms were included in a variety of statistical analyses to determine co-variation between variables, noise thresholds for sleep disturbance and awakenings, and risk for poor sleep quality; however, a relatively small sample size and high variability in a number of the measures resulted in inconclusive findings. In another sleep study, polysomnographic (PSG) signals were collected from study participants while simultaneously recording sound pressure levels with instrumentation that was responsive to very low frequencies (e.g., 1 Hz). Sixteen healthy subjects were studied before and then after a wind power facility became operational. Different noise exposure parameters were calculated (Laeq, Lzeq) and analyzed in relation to whole-night sleep parameters. Sleep parameters were not significantly changed after exposure. However, self-reported sleep qualities were significantly ($p=0.008$) worsened after exposure. Average noise levels during the exposure period were low to moderate and the mean of inside noise levels did not significantly change after exposure. Although these sleep studies failed to demonstrate an association between wind turbine noise and sleep disturbances based on findings using PSG and actigraphy data, the finding of self-reported poorer sleep quality suggests that further studies are needed. Factors other than noise levels may be impacting sleep and future work examining noise character and non-noise exposures is in order. Also, instead of taking a population approach in which wind turbine noise exposures are close to normal, more of a case study approach focusing on close to the worst-case scenario would be more likely to detect differences. Similarly, as opposed to selecting participants who are healthy, intensively studying individuals who have symptoms attributable to exposure to wind turbine noise may provide valuable findings.

Epidemiological investigations were also carried out in order to study the health impacts of wind turbines. After preliminary studies to develop the survey instruments, 200 surveys were delivered to homes within 3 km of wind turbines in the township of Thamesville. The response rate of 22.5 % was modest but provided sufficient statistical power to examine the psychometric properties of the scales. Subsequently, the full scale investigation began with the distribution of surveys to 5000 homes across eight communities with wind generation facilities. Despite following best practices for survey administration which included multiple follow-ups and media releases, the response rate was only 8.5%. Based on an analysis of 396 respondents a correlation between scores on the Pittsburg Sleep

Quality Index and the log of distance from the nearest wind turbine was statistically significant with sleep improving with increasing distance. Similarly, reported symptoms such as vertigo also lessened with increasing distances from the turbines. Although these correlations remained significant after controlling for potential confounders the findings must be viewed as inconclusive because of the low response rate and possibility of selection bias. The same survey was used in a smaller before after study of wind turbine exposures and these findings we not observed albeit the statistical power was much lower. A section on the questionnaire distributed to residents in the eight communities pertained to follow-up clinical and biomonitoring data collection. A total of 20 individuals agreed to the follow-up and were contacted by researchers and provided hair and saliva samples over a three day period. No significant differences in mean cortisol levels in either biological media were associated with distance from the closest wind turbine or other indicators of wind turbine related exposures. The small sample size makes it very difficult to draw conclusions because of the low statistical power.

Geographical information System technology was used to identify locations of individual wind turbines and residences for the epidemiological investigations. Pilot work for the epidemiology study used GIS data to identify specific residences for targeted survey delivery, however a more logistically feasible approach of providing surveys to all residents within Canada Post Delivery Unit shapefiles was selected. In the analysis of 396 respondents who participated in the epidemiology study a sample was selected and geo location data was used to in analyses to examine dose-response relationships.

Psychosocial factors were also investigated to analyze any relationship with reported health effects of wind turbines. This risk communication research examined newspaper reporting of the health effects of wind turbines before and after the Green Energy Act. The aim was to provide insights into the public discourse about health risk perceptions of people living in Ontario communities where wind turbines are placed. In analysis of 421 articles from 13 community and 4 provincial newspapers, fright factors of dread, poorly understood by science, inequitable distribution, and inescapable exposure occurred more frequently in community newspaper articles than in provincial ones ($p < 0.001$). The number of occurrences of each fright factor increased following the Green Energy Act. However, only dread ($p < 0.05$) and poorly understood by science ($p < 0.01$) occurred more frequently after the Green Energy Act. These findings suggest the public's general anxiety and lack of thorough understanding of the potential health effects from exposure to wind energy developments. Greater attention to the perceived lack of understanding and anxiety about health effects from wind energy developments may improve risk communication about these technologies.

As part of the epidemiological study conducted across eight communities in Ontario the researchers were able to examine the relationship of psychosocial factors with self-reported health. Scales addressing perceptions of wind turbines, risk perceptions, housing and community, sleep, and health were first examined using psychometric techniques. The resulting factors were described as 'health and environment concerns', 'financial concerns', 'wind turbine sensitivity', and 'community capital'. When these factors were compared to health outcomes it was found that health, measured through self-reported mental health, physical health, and sleep, was lower in community members with negative opinions or concerns about wind turbine development. The potential for perceptions to mediate the relationship between wind turbine exposure and reported health effects is an important addition to environmental health theory. In order to better understand psychosocial factors and self-reported general health in residents close to wind power facilities, a before after study of 40 residents was

completed. Prospective cohort data were collected before and after WT operations. General health and quality of life metrics were measured using standard scales, such as SF12, satisfaction with life (SWL) scales developed by Diener (SWLS) and the Canadian Community Health Survey (CCHS-SWL), and a newly created scale for WT-related health effects, named the Wind Turbine Syndrome Index (WTSI). The mean values for the Mental Component Score ($p<0.001$), SWLS ($p=0.002$), WTSI ($p<0.001$), and CCHS-SWL ($p=0.048$) significantly worsened after WT operation for those participants who had a negative attitude to WTs, who reported being visually or noise annoyed, and who voiced concerns about property devaluation. The findings suggest an association between a number of psychosocial factors and health and well-being of residents living close to wind turbines.

A constant-comparison case study was also carried out to capture experiences with wind turbines to determine which characteristics of development led to acceptance or opposition towards wind turbines, and to utilize the greater understanding of these experiences constructively to suggest improvements to the development process and add to energy planning theory. Interviews with 24 MPPs, members of local government, and community members were conducted and the data analyzed using a modified grounded theory approach. A key finding was that perceived inequalities were the main source of opposition related to wind turbines. These inequalities occur between neighbors, within communities, and within the province. This finding suggest that community ownership of wind turbines could reduce feelings of inequality and increase acceptance.

A research activity aimed at studying noise propagation from wind turbines was also undertaken. In this study existing models used to predict the degree of attenuation of sound intensity were compared. Measurements in wind turbine areas along with model algorithms from existing noise prediction models (ISO 9613, Dutch InfoMil, New Zealand Standard 6808) were used to develop a code for sound mapping that is appropriate for weather and ground conditions in Ontario. Results from these investigations provided evidence that there is likely minimal air absorption or ground effects on attenuation of low frequency wind turbine sounds and that such sound would be detectable 5 to 10 Km from the turbine.
Furthermore, in order to predict the noise source of wind turbine airfoils, a novel computational numerical sound source localization methodology that combines computational fluid dynamics simulation and experimental acoustic beamforming was employed. The developed method, which takes into account the directivity of sound source emission, helps in the optimization of beamforming algorithms and microphone array designs, and also makes sound source prediction of large structures in the low frequency range possible. The research resulted in the proposal of a new method of Computational Acoustic Beamforming.

An important consideration on the safety aspects of wind turbines, and any large structures for that matter, is the structural health monitoring. In this regard a research activity was initiated for sensing and monitoring the strain in wind turbine blades. The first phase of the research included the design of strain sensors with high linearity and sensitivity along with enhanced strain transfer mechanisms. New designs for micro-sensors have been developed to convert the strain-produced horizontal displacement into vertical movement with enhanced sensitivity through mechanical amplification. Studies on the effects of interfacial adhesive materials and their mechanical properties on the transfer of strain from the host structure to the sensor resulted in architectures with maximal strain transfer. In the second phase a new multi-sensor data fusion method was proposed to non-destructively locate and estimate

the severity of damage in wind turbine blades. Since data from individual sensors may not be very reliable and often not provide complete information, data fusion was proposed for an improved detection system that provides a more robust reading with reduced false alarms. Fusing data from multiple sensors allows to make inferences that are generally not possible with individual sensors. In addition, the proposed technique has the enhanced capability for real-time damage detection. In the third phase microelectromechanical systems technology was used to experimentally fabricate strain sensors with high sensitivity. The performance of the fabricated sensors has been verified by mounting them to host surfaces and measuring the capacitance signals for different strain levels.

The ORC research also included a reliability and operational safety study concerning grid-connected photovoltaic systems. The focus of this research was on the harmonic analysis of LCL filter degradations in the inverter electronics. This study, performed using model-based simulations, underlined that the parametric degradation over time of the inverter and filter components can add to the total harmonic distortion of the system. As an extension of the inverter study, principally aimed at building integrated or roof-top PV systems, a dynamic-routing of power from individual modules to inverters was proposed based on a 0-1 multiple knapsack problem. Based on the simulations it was shown that the proposed dynamic routing can increase the efficiency of the PV system by 2% and decrease the total harmonic distortion up to 6% at worst conditions of shading.

Another study was undertaken to analyze the challenges in the grid integration of different renewable energy sources such as solar, wind, bio etc. Power electronics computer simulations were used to analyze the system where hybrid renewable energy sources are treated as distributed generators, and power flow modeling was done to investigate the overloading issue. The effect of the distributed generator on the power flow (real and reactive) on the main grid was estimated. The study underlined the need for power flow analyses in hybrid systems prior to installation. Furthermore, the study also showed that fault currents can be altered by added distributed generators and that both fuse sizing and tie-up locations influence the system reliability.

The ORC research also covered a topic on bio energy, where research was initiated with the objective of developing a sustainable technology to convert biomass to biofuels. In this context a hydrothermal conversion method was investigated in laboratory setting. Experiments involving single and mixed solvents of different polarity carried to explore the extraction of 5-hydroxymethyl furfural biofuel precursor. The results showed that the extraction of 5-hydroxymethyl furfural from hydrothermal conversion products is possible and it depends on solvent polarity, salt concentration, and pH level of the solvent.

Another ORC research activity addressed one of the end-of-life recycling challenges of solar photovoltaic modules. Presence of hazardous materials such as silver and lead in the metallization needs to be minimized and this should also make it easier to recover the silicon material from used-up modules. In parallel, this research also addressed an important manufacturing obstacle paused by the traditional thick-film metallization process for the future ultra-thin silicon wafer solar cells. Alternatives to the silver pastes that are currently used for metal contacts have been investigated by introducing new, polymer-based conductive pastes. Another advantage is that the new polymeric compounds studied require much lower firing temperatures than the traditional metal pastes and hence are compatible with shallow junction solar cells which are more efficient. The work resulted in the

development of a polymeric paste that is screen-printable and has a conductivity that is comparable to metal pastes.

The ORC research also covered toxicity and safety studies on the use of new, nano-materials for next generation solar cells. The focus was on the fabrication and processing environments of quantum dots that are potential candidates for future photovoltaic devices. The occurrence and effects of air-borne nano particles were systematically studied during controlled chemical synthesis and layer formation processes, to evaluate the degrees of cross-contamination and toxicity. The degree of particle spread was by analyzing specimens by inductively coupled plasma mass spectroscopy. The toxicity was studied in collaboration with the department of Biology. Potential cytotoxicity effects on mammalian cells were evaluated by conducting HeLa cell studies. The HeLa cells were exposed to different quantum dot materials that were also processed with various ligands. These studies resulted in vital information on the degree of particle spread and toxicity, and can form the basis for future scale-up of the new technologies. Furthermore, copper-indium-sulfide (CIS) based quantum dot processing was found to be the most benign from a toxicity viewpoint. Based on this, the research team has also developed processes to synthesize colloidal CIS- quantum dot solutions that are scalable and useful in future solar cell and other optoelectronic applications.

Brief Overview of Results and Accomplishments – Part 2

Indicator	Results
Publications	Publications related to the ORC research by team members: • Journal papers: 33 • Conference proceedings: 18 • Book chapters: 3
Students supervised	Students supervised and trained over the five years on ORC research topics: • Postdoctoral fellows: 3 • PhD students: 11 • Masters students: 12 • Undergrad Students (incl. Nursing students from McMaster U.):14
Presentations	Oral and poster presentations made by team members on ORC research topics: • Total presentations: 22
Meetings attended	Research conferences, symposia, and workshops attended by team members: • Total number of meetings: 41
Partnerships	Engagement and linkages developed in relation to the ORC research: <u>Internal</u>: • Prof. John Vanderkooy (Physics): Noise measurements/modeling • Prof. Sriram Narasimhan (Civil Eng.): Noise measurements/modeling • Prof. Niels Bols (Biology): Toxicity analysis • Prof. John Mielke (School of Public Health): Cortisol analysis • Prof. Geoffrey Lewis (School of Planning): Energy planning • Prof. Susan Elliot (Geography and Env. Management): Medical geography • Prof. Jeff Aramani (School of Public Health): Environmental Epidemiology • Prof. Diane Williams (School of Public Health): Auditory Neuroscience • Prof. Laura Johnson (School of Planning): Sociology <u>External</u>: • Prof. Ramani Ramakrishnan (Ryerson U.): Noise measurement • Prof. Jamie Baxter (Western U.): Community hazard response • Prof. Sasan Adibi (Deakin U., Australia): Mobile tech for sleep assessment • Niagara Region Public Health • Accq SleepLabs Kitchener-Waterloo • School of Nursing – McMaster University • School of Nursing – Conestoga College • Academic Health System (Doha, Qatar)

Indicator	Results
Dissemination of research results	In addition to the dissemination venues of journal publications and conference presentations, the researchers also interacted with public and public policy makers. Such outreach examples include: • COU symposia (2010, 2013) • Engineers' PD day (Ministry of Environment 2012) • Mountain & Plains ERC Energy Summit (Colorado, 2011) • Social & Community Aspects Of Wind Power in Ontario Workshop (2015) • Energy Council of Canada Canadian Energy Summit (2015) • Radio and media interviews (e.g. CBC, Sun News Network, Blackburn radio, Blackburn News, London Free Press, Chatham Kent Daily Post) • Environmental Review Tribunal (2014) • International Society for Environmental Epidemiology (Seattle, 2013) • Science in the Wind event – Laurentian University (2013) • Ontario Network for Sustainable Energy Workshop (2013) • Policy Makers' Round Table – Canadian Public Health association (2012) • Town Hall Meeting – Niagara Region Council (2013)